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Glen H. Egstrom
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Allan D. Baddeley
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This report presents findings of the research efforts for 1971 in the study of underwater work performance and work tolerance conducted at the University of California, Los Angeles. The studies were directed towards the development of performance decrement curves related to the specific variables which affect underwater work. Experiments designed to add to the body of knowledge necessary to the formation of decrement curves were conducted. The experiments examined: (a) the effect of cold-water exposure upon memory, reasoning ability, and vigilance, (b) the effect of depth upon memory, (c) wet vs. dry training for a specific underwater task, and (d) the physiological and performance effects of heliox as a breathing gas in cold water. The corresponding results show that: (a) cold-water exposure impairs memory but not reasoning ability or vigilance, (b) although narcotic impairment to depths of 110 feet are small, material learned underwater is not remembered well on the surface, (c) training underwater for a specific underwater task is preferable to dry-land training, and (d) physiological state changes and performance levels in cold water are not substantially different for heliox as compared to air for a wetsuited diver. These data and the data from the literature are incorporated and presented as framework for the performance decrement curves.

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PREFACE

The work described in this report, "Underwater Work Performance and Work Tolerance," was carried on under the direction of Glen H. Egstrom, Principal Investigator and Gershon Weltman, Co-principal Investigator in the School of Engineering and Applied Science, University of California, Los Angeles. Alan Baddeley, from the Laboratory of Experimental Psychology, University of Sussex, was a visiting researcher during the summer period.

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Whatever contributions we have been able to make to the methology of underwater research would not have been possible without the dedicated assistance of our ONR sponsors: Mr. Gerald Malecki has worked with us throughout the life of the project. Dr. Martin Tolcott, Head of the Engineering Psychology Branch, Washington, D.C., has helped guide this year's studies. Dr. Eugene Gloye of the Pasadena Office has taken an active interest in our experiments and results. Appreciation also goes to Dr. Arthur Bachrach, Director, Behavioral Science Laboratory, Naval Medical Research Institute, for his support.

We wish to thank these people and also the other navy personnel, the many students, and most of all, the unsung subjects, who have all contributed to an enjoyable, as well as fruitful, undertaking. Special recognition is given to the Commercial Diving Center in Wilmington, California, for their assistance in various phases of the study.

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SUMMARY

This report presents findings of the research efforts for 1971 in the study of underwater work performance and work tolerance conducted at the University of California, Los Angeles. The studies were directed towards the development of performance decrement curves related to the specific variables which affect underwater work. Experiments designed to add to the body of knowledge necessary to the formation of decrement curves were conducted. The following sections summarize briefly the principal findings:

1) Underwater Work Tolerance. The concept of a system which could predict diver work effectiveness under specific conditions was developed. Performance decrement curves and, ultimately, work tolerance tables would provide an information base for the system. The research effort concentrated primarily upon the establishment of the performance decrement curves. An extensive review of the literature revealed that the data now available was not adequate for establishing immediately useful decrement curves. Considerable more work is required before the decrement curves can become useful tools. As a foundation for the decrement curves, data from the literature and the data reported in this document are offered.

2) Cold Water Exposure. A study was conducted to examine the effects of cold water exposure upon cognitive efficiency. Memory, reasoning ability, and vigilance were examined for fourteen subjects who were exposed to 40° F. and 80° F. water. Vigilance to peripheral visual stimulus during performance of a central task was tested. Reasoning ability was tested via a sentence comprehension test which was administered at the beginning and end of a one-hour exposure. Memory of material learned underwater after a one-hour exposure was measured. Recall and recognition tests were administered approximately thirty minutes after the diver surfaced. Although a mean fall in rectal temperature of 1.3° F. was recorded, vigilance and reasoning ability were unaffected by the cold; memory, however, was significantly impaired. An interpretation of the memory impairment in terms of state-dependency is suggested.

3) Memory Underwater. Divers spent five minutes memorizing a prose passage either on board a diving boat or at a depth of 15 or 110 feet in the open sea. They surfaced, and after a 30-minute delay, recall and recognition of the passage by all three groups was tested. Recall of material learned at 15 feet was worse than that learned on the surface, but no difference was found between recall at the two depths. There was no impairment in recognition performance. These results support the interpretation of the recall decrement in terms of state-dependent memory. The practical implications of these results are discussed.

SUMMARY

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4) Training. The UCLA pipe puzzle construction task was performed by a group of divers who trained for the task on dry-land and by a group who trained underwater. Task completion time and error production were used as indicators of efficiency. The water-trained group was consistently faster in all phases of the task. There was no difference in error production between the two groups. The results of this pilot indicate that training on dry-land is not as effective as wet training in preparing divers for complex task performance.

5) Heliox and Physiologic State. A study was conducted in order to determine the physiological and work performance effects of breathing a heliox mixture as compared to breathing air in 42° F. water. Twelve wetsuited subjects performed the UCLA pipe puzzle task twice, once while breathing an 80% helium - 20% oxygen mixture and once while breathing air. As indicators of physiologic state, heart rate, respiratory minute volume, and rectal temperature were monitored. Task completion time and error production provided a measure of task performance. The results show that heliox does not affect a wetsuited diver's ability to work, and that his physiologic state is slightly different than that for air. Heartrates were slightly higher and minute volume larger during the heliox trials. Mean rectal temperature fell more during the air trials.

6) Navy-Makai Diving Operations. These operations involved a 200-foot dive of the Aegir submersable work station which was accomplished, and a 500-foot dive which was not. The UCLA contribution to these operations was a Study of Diver Performance in Underwater Construction Tasks, conducted as part of the ocean-floor experimental program. This study is described in detail in a forthcoming ONR report. Section VI of this report is a brief summary of the study.

I. WORK TOLERANCE TABLES

A review of the history of man's efforts to develop effective underwater work capabilities leads to the recognition that highly specific adaptations are made to the imposed demands of the environment, the problem requiring solution and the equipment used. The concept that diving is a generalized skill which can be applied to any underwater work situation by a diver has been modified to accept the fact that diving is a means of supporting life and transporting a diver to a work site. There the actual task then requires all of the art and science associated with any other highly complex technology, and performance decrements can be anticipated as intervening variables are introduced.

The current year's effort on underwater work measurement and diver effectiveness has reinforced our belief that there is a definite need for the development of performance decrement curves related to the specific variables that affect underwater work. Work tolerance tables that can be used to quantify the effects of these variables should ultimately be feasible. Performance curves and work tolerance tables would provide several advantages to underwater programs.

1. The performance decrement data would identify the important variables and provide for a synthesis of the effect of particular variables on underwater work performance. Using cold as an example, it appears feasible to develop data which would identify a predicted decrement in memory, vigilance, etc. for a given range of water temperatures as a function of exposure time. This data might indicate no significant differences until certain critical levels of exposure were reached and then follow a decrement curve along the time line.

2. The curves and tables which would be established would enable the diving supervisor or underwater work planner to make predictions as to the effectivenss of the diver operating in a specific work environment.

3. Projections for the modification of underwater work methods, equipment and environmental controls could be based upon objective evidence rather than speculation.

4. Identification of "safe limits" could be used to permit monitors to be used for controlling dives.

The ultimate validity of such a system will require extensive testing in the field, but immediate gains in understanding the decrements will result from the synthesis of existing data.

The basic concept involved in underwater work tolerance tables provides for the development of a predictive tool. This tool could be utilized in planning for safe, effective diving operations under a wide range of conditions. It is recognized that only fairly gross decisions are possible until a reliable data bank is obtained. It is, however, felt that the initial development of such tables should show marked benefits in identifying the critical variables which will effect the diver's work behavior.

The diagrams contained in this document represent an example of the methodology encorporated in using such tables. Figure I-1 represents the generalized decision system. Immediate physical and physiologic data serves two functions. First, it provides a current picture of the state of the diver and the environment; and second, it provides information relative to the modification of the effective environment. The effective environment consists of a reduced number of variables as a result of synthesizing obviously interdependent specifics. For example, the effective temperature would be the produce of water temperature, diver insulation, metabolic level, time, etc. The effective temperature would exert different levels of influence on the periphery and the core.

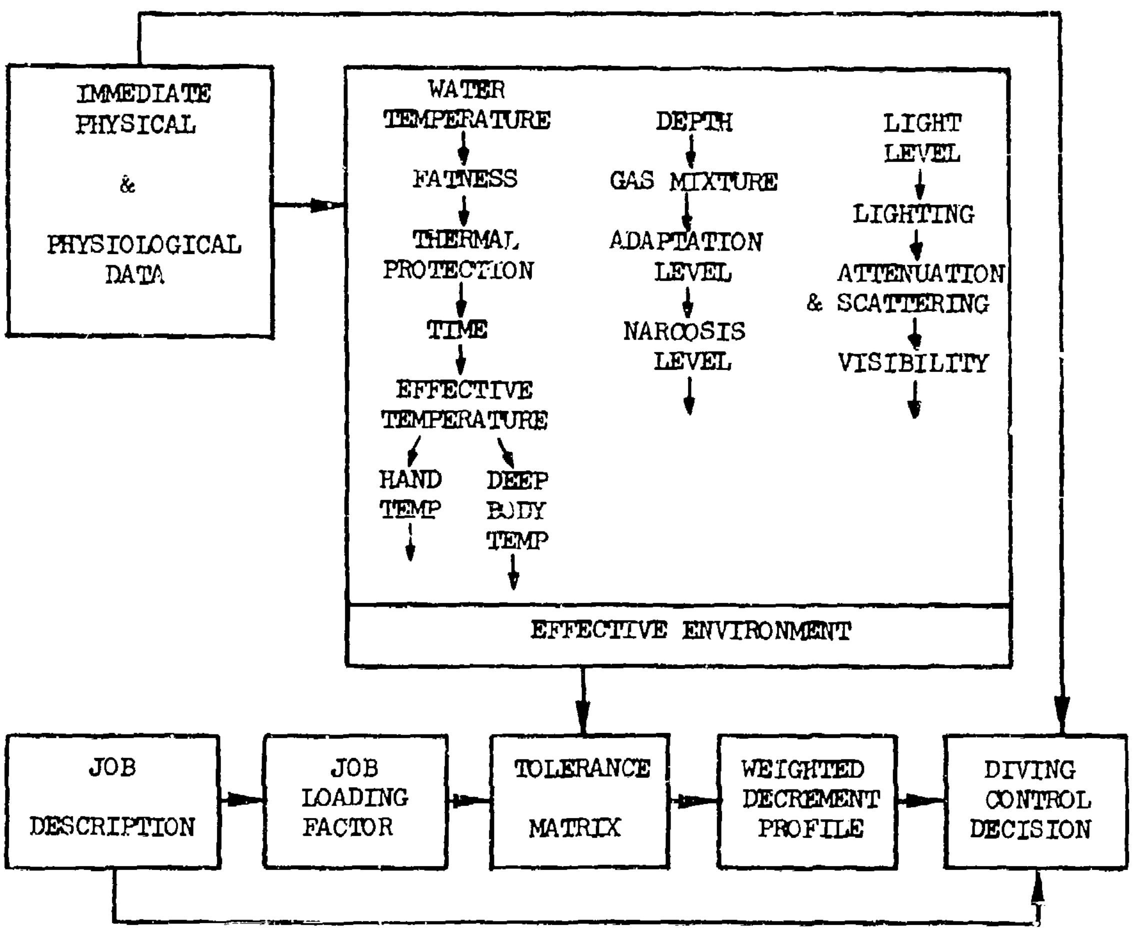

Figure I-1. GENERALIZED DECISION SYSTEM

In Table I-1, the effective environment would be expected to exert its influence on Task Performance Factors. This influence would then be ranked from 1 to 5, with 5 being the highest level of expected decrement. Each of the effective environment decrements for a factor would then be accumulated and multiplied by a job loading factor.

This factor would result from data drawn from the available literature and current practice reviews (work records and diving logs) The resultant Weignted Decrement Profile could establish the relative decrement to be expected for a gi[illegible] task performance factor. The decrements would then be totaled, [illegible] a percentage decrement for the particular person under the exist[illegible] onditions could be expressed. With this information at hand, a decision could be rendered.

The values entered into Table I-1 describe, for example, a routine assembly task in cold, shallow water, fair visibility, some swell and low risk. The predicted decrement for this task is 16.8%.

TABLE I-1
TOLERANCE MATRIX

TASK PERFORMANCE FACTORS	EFFECTIVE ENVIRONMENT										
	HAND TEMP.	BODY TEMP.	NARCOSIS	STABILITY	VISIBILITY	CAPABILITY	ANXIETY	FATIGUE	TOTAL	JOB LOADING FACTOR(/10)	WEIGHTED DECREMENT PROFILE
PHYSICAL WORK CAPACITY	2	0	0	2	0	1	0	1	6	7	42
SENSORI-MOTOR SKILLS	4	0	0	3	1	2	0	1	11	5	55
PERCEPTUAL	0	0	0	1	2	0	1	0	4	1	4
COGNITIVE	0	0	0	0	0	0	0	0	0	2	0

101/600(MAX)
=
16.8% DECREMENT

It is recognized that the performance decrement curves for the individual variables related to underwater work must be developed prior to any synthesis.

As the work on the performance decrement curves progressed, it became apparent that attempts to synthesize these curves into tables with predictive capability was virtually impossible. This was due in large measure to the variability in data gathering and reporting techniques used by the various investigators. So great is the variability that even performance decrement curves which we were developing for purposes of identifying gaps in the existing literature were of little practical value. It is obvious that efforts directed toward developing meaningful decrement curves will require considerably more work than was originally proposed.

The curves which are presented in Figures I-2 through I-7 represent the present state of knowledge in these areas. Much of the information has been extrapolated from data which is not precisely comparable. As the data bank improves; however, the accuracy of the curves should improve proportionately.

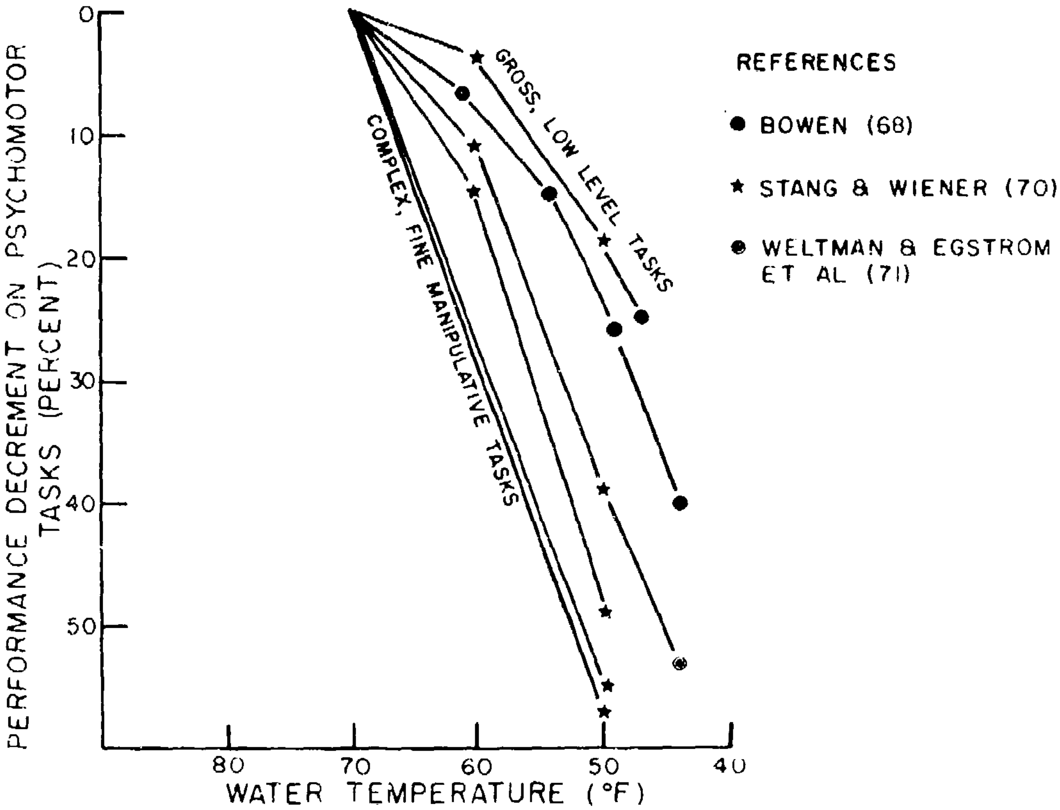

Figure I-2. PERCENT PERFORMANCE DECREMENT ON PSYCHOMOTOR TASKS AS A FUNCTION OF WATER TEMPERATURE AND TASK COMPLEXITY

Psychomotor performance is severely degraded by cold water exposure. The degree of impairment is a function of exposure severity. Activities that require fine manipulation are impaired more than those that require gross movements. For example, Stang and Wiener (1970) observed a 19% decrement on a speed wrench test that required gross movements and a 57% decrement on a screwplate test that required fine manipulation.

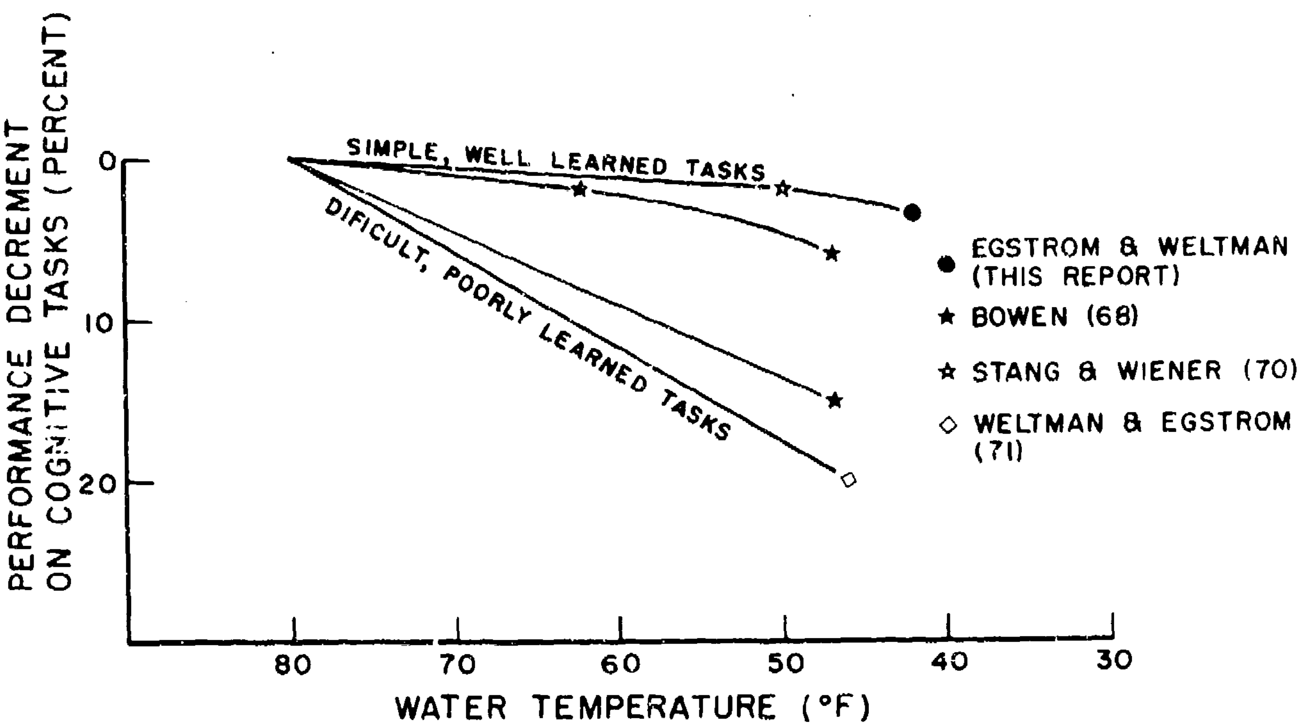

Figure I-3. PERCENT PERFORMANCE DECREMENT IN COGNITIVE TASKS AS A FUNCTION OF WATER TEMPERATURE AND TASK COMPLEXITY

The effect of cold water exposure on cognitive performance is not well defined. Clearly more data is needed before reasonably accurate predictions can be made. In light of the existing data on tasks heavily relying on reasoning ability, it appears that performance on simple or well learned, complex tasks are minimally impaired. Complex tasks with which the diver is not familiar are impaired to a greater extent. Experience on the cognitive task at hand should, therefore, be a factor when predicting cognitive performance.

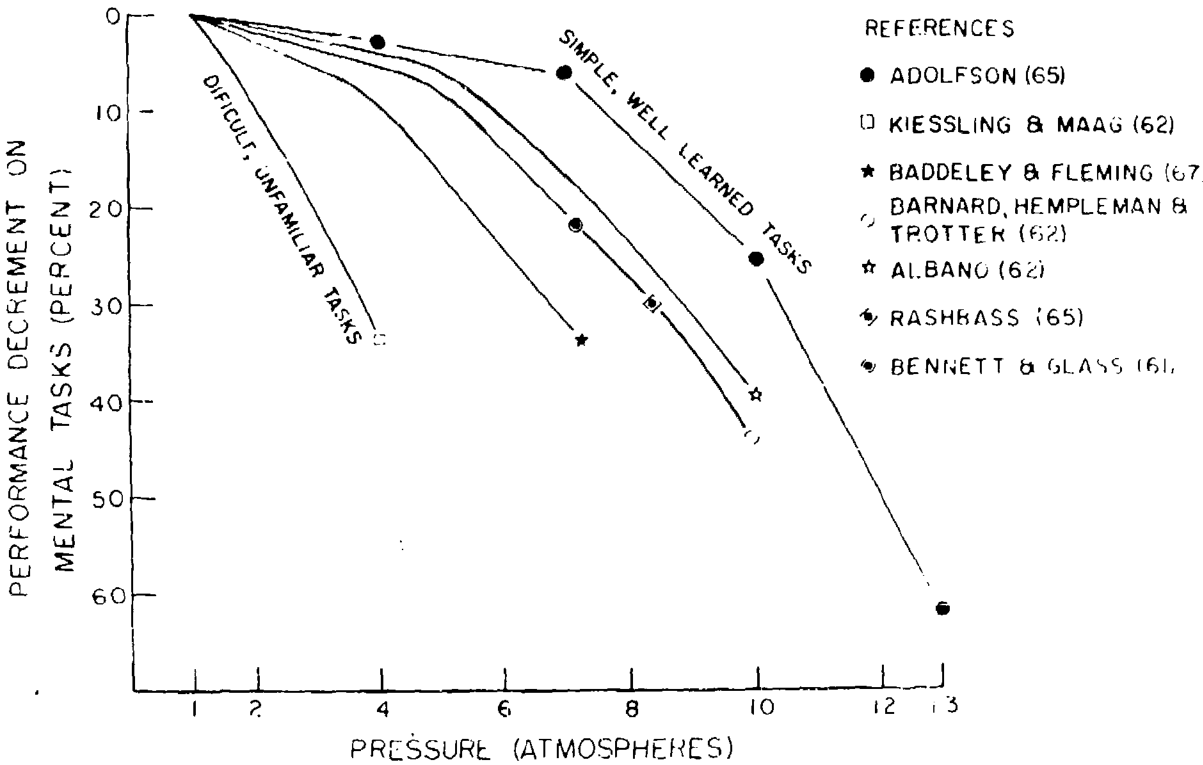

Figure I-4. PERCENT PERFORMANCE DECREMENT ON MENTAL TASKS AS A FUNCTION OF PRESSURE AND TASK COMPLEXITY

The effect of hyperbaric air on cognitive performance reported by various investigators varies widely. There does, however, seem to be a correlation between task complexity and degree of impairment. Adolfson (1965) observed a 25% decrement on an arithmetic test at 10 atmospheres; whereas, Kiessling and Maag (1962) observed a 33% decrement on a complex conceptual reasoning test at only 4 atmospheres. The degree of cognitive loading should apparently be weighted quite heavily when predicting task performance.

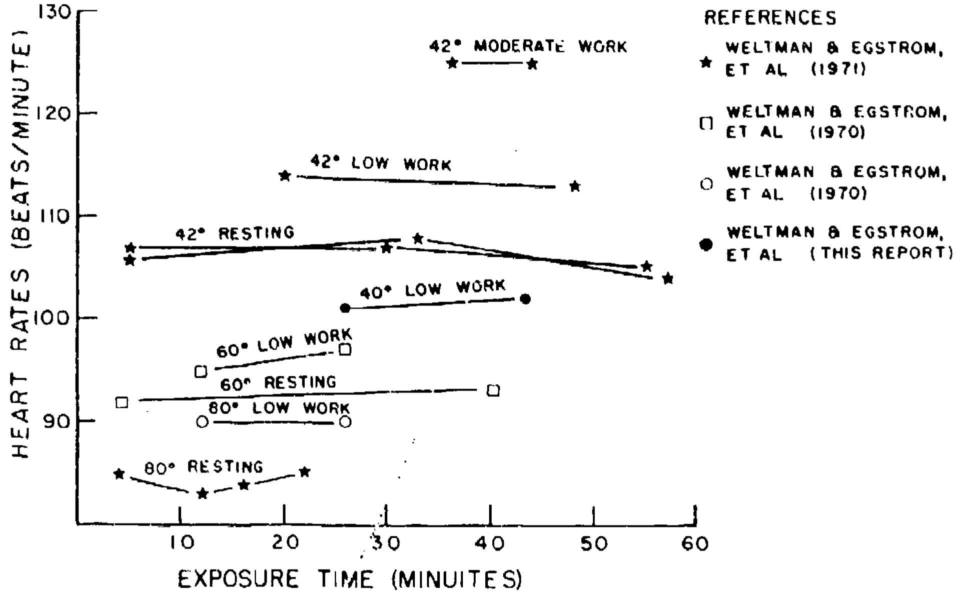

Figure I-5 HEART RATES FOR VARIOUS WATER TEMPERATURES AND EXPOSURE TIME

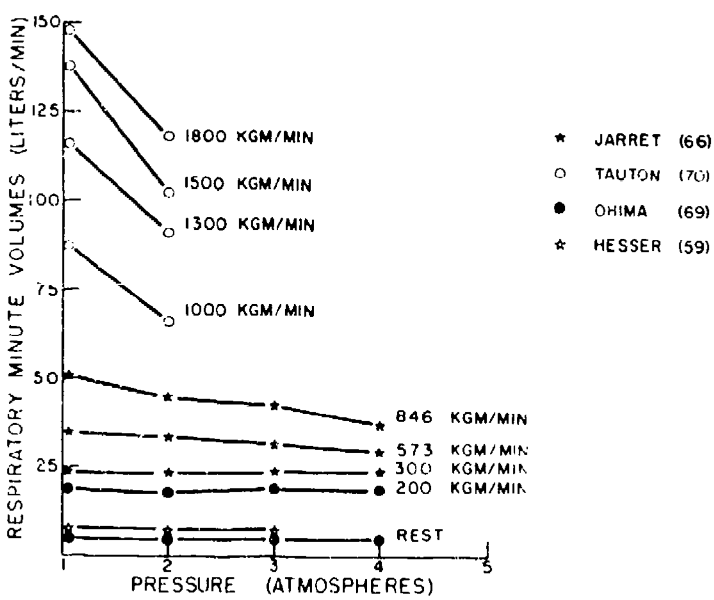

Figure I-6 RESPIRATORY MINUTE VOLUME AS A FUNCTION OF WORK RATE AND PRESSURE

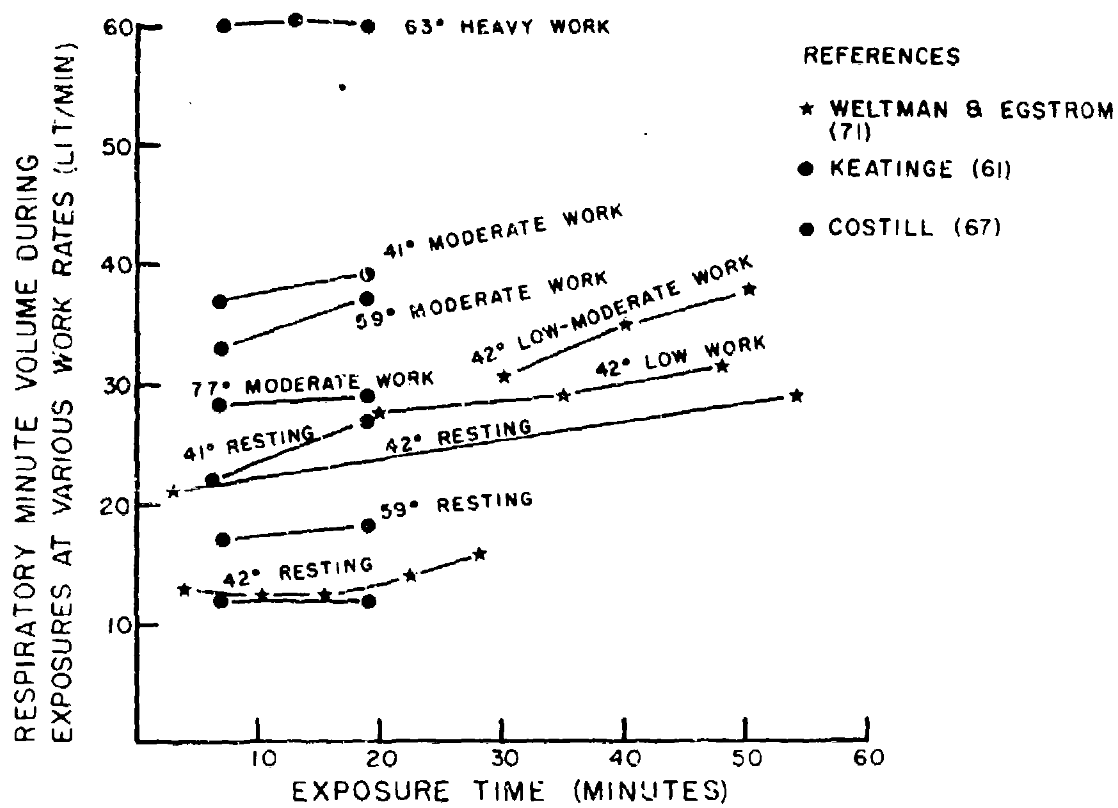

Figure I-7. RESPIRATORY MINUTE VOLUME AS A FUNCTION OF WORK RATE, WATER TEMPERATURE, AND EXPOSURE TIME

II. COGNITIVE EFFICIENCY OF DIVERS WORKING IN COLD WATER

INTRODUCTION

It is frequently necessary for a diver to work in cold water; and despite advances in thermal protection, he is likely to experience a significant drop in body temperature. There is abundant evidence that this will impair his manual dexterity (Fox, 1967; Bowen, 1968; Stang and Wiener, 1970), but there is very little evidence that cold had an adverse effect on his cognitive efficiency.

Bowen (1968) did in fact study a number of cognitive tasks. They found some slight evidence for impairment and tentatively suggest that "cold water stress, in addition to causing specific sensory and motor losses, causes increasing losses of capability as the task becomes more complex and is more dependent on sustained attention and memory functions" (Bowen, 1968). The only other evidence for such an impairment comes from a study of time estimation in divers (Baddeley, 1966) in which the estimated duration of a minute increased after diving in cold (4° C.) water, and from a recent study by Stang and Wiener (1970) who found an increase in two-choice reaction time. However, in view of Teichner's (1954) failure to find an effect of cold on reaction time, it seems possible that this slowing of response may have been due to impaired manual dexterity rather than to slower information processing.

With the growing technical sophistication of underwater work, the cognitive demands placed upon a diver are increasing. It is therefore important that this gap in our knowledge of the effects of cold stress should be filled. The present study is a step in this direction. The performance of divers on tests of reasoning, vigilance, memory, and pipe puzzle assembly task was studied when performed in warm water (78° F.) and in cold water (40° F.)

METHOD

A. Reasoning Test

The test used was devised by Baddeley (1968). The subjects are required to judge as true or false a series of sentences. Each sentence claims to describe the order of two letters A and B and is followed by either of the letter pairs AB or BA. For example, "A is not preceded by B -- BA." To properly respond, the subject should answer false. Performance speed has been shown to be correlated with intelligence, and the test has proven to be sensitive to a range of stresses (Baddeley, 1968). Our procedure was slightly modified from Baddeley in order to present each sentence individually and to measure individual response time and accuracy. The sentences were projected by a 35 mm slide projector onto the back of a frosted glass viewing screen which was placed at one of the observation ports of the diving tank. The sentences were easily seen by the diver subject standing in the tank at the observation port. The subject responded by moving the lever of an underwater switch to the left for true and to the right for false. The underwater switch was connected to a display unit in the instrumentation room which presented the subject's answer to the experimenter. An electronic timer was incorporated into the system to measure the interval from the onset of sentence presentation to the subject's response with the switch. The experimenter recorded the answer and the response time. He then cycled the system for the next presentation. A large lever (5 inches) on the switch was used to minimize the effects of impaired manual dexterity. To provide a further check, an estimate of reaction time with minimal cognitive load was obtained by including slides containing only the word "true" or the word "false" in upper-case letters. The subjects were simply to respond accordingly. A sketch of the system is presented in figure II-1.

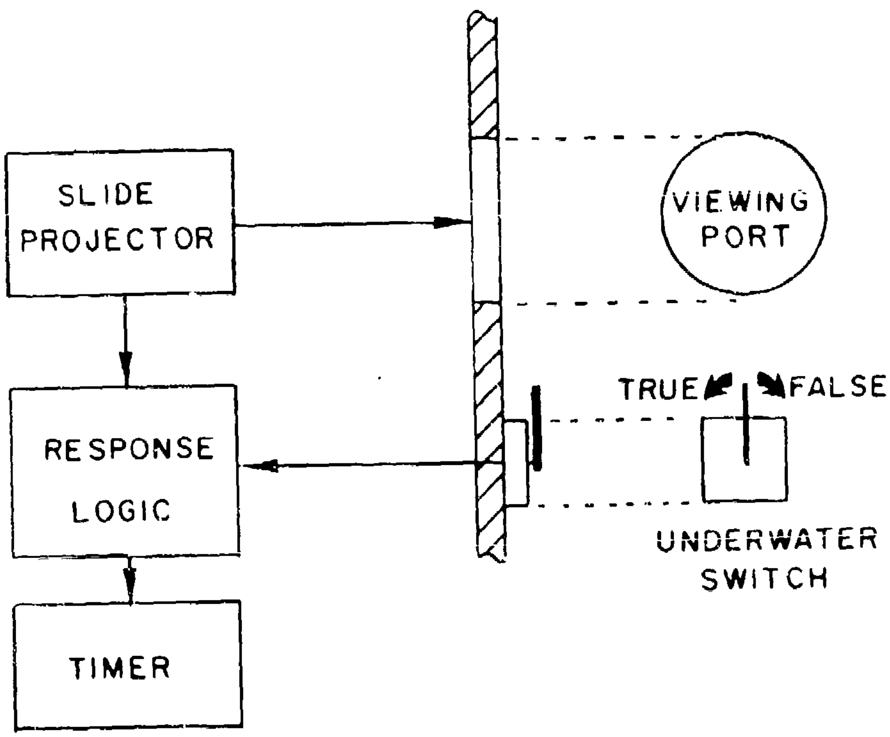

Figure II-1. REASONING TEST SYSTEM CONFIGURATION

During each dive, subjects were tested twice - once at the beginning of the dive and once at the end. Each test run was comprised of a random sequence of 16 sentences and 5 "TRUE" and 5 "FALSE" slides. Initially, subjects were trained for the task on land, using the standard written form of the test (Baddeley, 1968). Subsequently, they trained using the experimental apparatus. The experimenter gave them knowledge of the results and discouraged them from making errors. This was followed by a training run in warm water and subsequently by the two test runs. Example tests are presented in the appendix.

B. Memory Test

A diver's ability to remember facts learned underwater was examined using the procedure devised by Friedman (1972) whereby a prose passage is created comprising a number of items, each being accompanied by information on several characteristics. The divers were later given a recall and a recognition test. For example, one passage described six underwater wrecks around an imaginary island. Each wreck was specified in five ways; the type of ship, its name, its depth, the nature of the surrounding sea bottom and the principal danger to a diver investigating it. Thus the passage contained a total of 30 "facts."

The subjects were tested simultaneously. Each was presented with a different passage at one of the two observation ports. They were allowed 5 minutes to memorize the passage. They were warned when 3 minutes had elapsed to help them distribute their learning time optimally. The passages were presented after the divers had been in the water approximately 45 minutes. Retention was tested after an interval of 40 minutes by which time they had completed the dive, had taken a hot shower, and dressed. First they were required to recall as much as possible of the passage, and then they were to perform a recognition test. This test was comprised of 24 true-false sentences about the passages, of which 12 were true and 12 were false.

A passage about girls was used for practice, and passages about wrecks and underwater jobs were used for experimental runs. Three separate recognition tests were used for each passage. Assignment of passages and recognition tests was counterbalanced across conditions. The specific passages and tests are given in the appendix.

C. Vigilence Test

The UCLA Underwater Construction Task was used as the primary loading task for the vigilance experiments. While the divers were working on the construction task, a small dim lamp which was mounted in the lower right visual periphery of the Kirby-Morgan band masks would flash. The lamp would stay lit for approximately two seconds. The interval between flashes varied randomly from 15 to 60 seconds. The diver was to respond verbally if he saw the flash.

Throughout the assembly and disassembly, independent channels presented the visual stimuli to the divers. The apparatus presented visual and audio signals to the experimenter when the subjects were presented with the stimuli. The experimenter scored the subjects on each presentation.

The UCLA Underwater Construction Task was simplified in this study by the omission of the dewatering and pressurization phase. The divers were required only to perform the assembly and disassembly phases. The assembled structure, shown in figure II-2, stands about six-feet tall on a four-by-five foot base. For a detailed description of the task, consult Weltman and Egstrom, et al (1971).

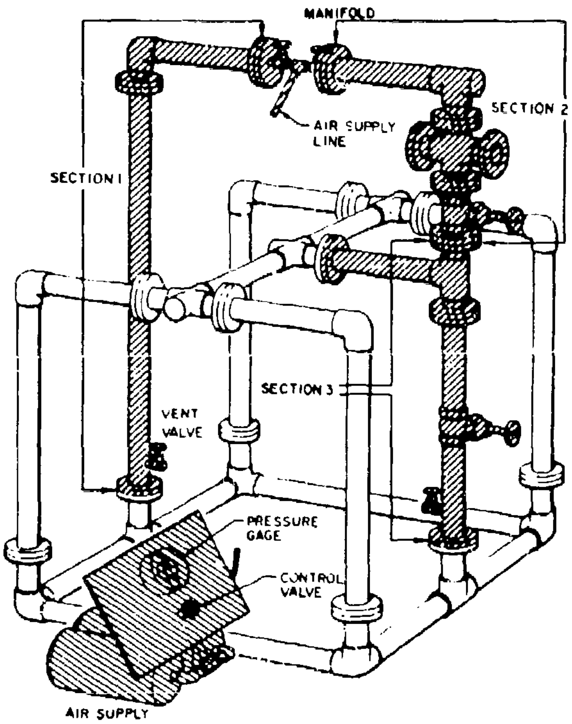

Figure II-2 UCLA UNDERWATER CONSTRUCTION TASK

Physiolgocial Data

Heartrate and rectal temperatures were the physiological indices recorded during the experimental exposures. We have found (Weltman and Egstrom et al., 1969, 1970, and 1971) that a diver's heartrate is a good indicator of physiologic workload. Rectal temperatures were used as an indicator of the diver's thermal state.

A. Heartrate

Electrodes were placed on both sides of the torso at about the fifth rib, lateral to the pectoralis muscle. This arrangement provides distinct QRS complexes from which heartrate can be derived. Both divers were similarly instrumented. The electrodes were connected by conductors attached to the umbilical to a physiological strip chart recorder. Data was later reduced by hand from the strip charts.

B. Rectal Temperatures

Bead thermistors were utilized in small, comfortable rectal probes to obtain rectal temperatures for both divers. The probes were inserted four inches into the diver's rectum. They were connected to a switching device via conductors attached to the umbilicals. The switching device, which in turn was connected to the strip chart recorder, allowed the recording of both rectal temperatures on the same channel of the strip chart recorder.

Experimental Protocol

Each two-man team visited the Underwater Research Facility three times. The first was an introductory and training run. The second and third were the experimental runs. Half of the subject group had their first experimental run in warm water and half in cold water. The training sessions began with a brief introduction to the various tests to be given. A dry-land training run on the construction task followed the introduction. The divers were then given extensive training on the reasoning and practice memory tests. Next, the divers suited up in their wetsuits and were given a warm water, construction task, training run. No vigilance presentations were made during these runs. Upon completion of the underwater training run, a second underwater training run was given. This run was a duplication of the experimental runs.

The schedule for an experimental run is diagrammed in Figure II-3.

Time per Task	5 min	5 min	35 minutes	5 min	5 min	5 min
Red Diver	Strength Test	Reasoning Test B	Construction Task with	Memorize Passage A	Strength Test	Reasoning Test A
White Diver	Reasoning Test A	Strength Test	Vigilance Task	Memorize Passage B	Reasoning Test B	Strength Test

Time 0 5 10 45 50 55 60

Figure II-3. SCHEDULE FOR SINGLE EXPERIMENTAL TRIALS

Upon entering the water, one diver (designated red diver for identification purposes) proceeded to the strength-testing device. For a period of five minutes he performed isometric force tests. Simultaneously, white diver was at one of the viewing ports in the diving tank performing the reasoning test. When the tests had been completed, the divers exchanged places and the tests were repeated. The construction and vigilance tasks followed for approximately thirty-five minutes. This varied from thirty to forty -five minutes depending on construction task completion times. Memorization of the passages for the memory test occupied the next five minutes. Finally, the strength and reasoning tests were repeated exactly as during the beginning of the run.

Locale

The experimental sessions for this study were conducted at the UCLA Underwater Research Facility. The primary component of the facility is the 16-foot deep, 16-foot diameter cylindrical diving tank. The tank is equipped with a large refrigeration unit and an oversized pool heating system that allows control of water temperature to within two-degrees farenheit over a range of 40° to 90°. Adjoining the tank is the instrumentation facility. Housed within this facility are all the physiologic monitoring systems, the breathing gas supply, and other diver support systems.

Test Conditions

The mean water temperature for the cold exposures was 40.5°F. with a range of 40° to 42° F. For the warm exposures, the mean water temperature was 78.4°F. with a range of 74° to 80° F. Visibility was unlimited and depth was 16 feet.

Subjects

The experimental design initially specified sixteen subjects. During the course of the experimentation, two of the subjects refused to continue due to extreme discomfort. One subject was from the warm exposure first group of subjects, the other was from the cold first group. The subject population was therefore reduced to fourteen. Physical data for the fourteen are presented in table II-1.

TABLE II-1
SUBJECT PHYSICAL DATA (N = 14).

	Mean	Range
Age	23	19-38
Height	5'-11"	5'-6" - 6'-4"
Weight	174 pounds	140 - 210

Personal Equipment

The divers wore full 1/4-inch neoprene wetsuits, 1/8-inch hooded vests, 1/4-inch booties, and gloves. Kirby-Morgan band masks, supplied from the surface, were the breathing apparatus used. The divers also wore fins and approximately 30-pound weight belts.

RESULTS

A. Reasoning Test

Table II-2 shows the mean simple response times measured with the TRUE/FALSE slides. There is obviously no reliable decrement due to cold either at the beginning of the exposures (test 1) or at the end of 50-minutes exposure (test 2). Errors were virtually non-existent on this task.

TABLE II-2

MEAN RESPONSE TIMES IN SECONDS FOR THE SIMPLE RESPONSE TIME TEST USING THE TRUE/FALSE SLIDES ($N = 14$)

CONDITION	Response Time (secs)		
	TEST 1	TEST 2	EXPOSURE DECREMENT
WARM	0.762	0.795	0.033
COLD	0.788	0.769	-0.019
COLD DECREMENT	0.026	-0.026	

Table II-3 shows mean response time and errors for the reasoning test. Comparisons of warm and cold exposures yield no evidence that speed of reasoning is effected by water temperature either initially (Wilcoxon sign rank test, $T = 45$, $N = 14$, $p > .1$) or at the end of the exposures ($T = 52$, $N = 14$, $p > .1$). Nor is there any effect of temperature on accuracy; five subjects were more accurate in the warm condition, three in the cold, and six were equally accurate in both.

TABLE II-3
MEAN RESPONSE TIMES AND ERROR RATE FOR THE REASONING TEST
IN THE WARM AND COLD EXPOSURES (N = 14)

CONDITION	RESPONSE TIME (SECS) TEST 1	TEST 2	EXPOSURE DECREMENT	TEST 1	TEST 2	EXPOSURE DECREMENT
WARM	3.263	3.306	0.043	12.5	12.5	0.0
COLD	3.281	3.242	-0.039	15.2	14.3	-0.9
COLD DECREMENT	0.018	-0.064		2.7	1.8	

B. Memory

Table II-4 shows the mean recall and recognition scores for the two conditions. Recall is scored in terms of the percentage of "facts" reported correctly out of the 30 presented (i.e. six objects each with five characteristics). Comparison using the Wilcoxon test indicated significantly poorer performance in the cold condition on recall ($T = 10$, $N = 14$, $p < .01$, 2 tail) and borderline significance on recognition ($T = 14$, $N = 12$, $p = .052$, 2 tail). The effect appears to be more marked in the case of recall, but there is no obvious way in which the recall and recognition scores may validly be compared.

TABLE II-4
THE MEAN NUMBER OF CORRECT RESPONSES FOR THE MEMORY TESTS
FOR THE WARM AND COLD EXPOSURES (N = 14 FOR THE
RECALL TEST AND N = 12 FOR THE RECOGNITION TEST)

CONDITION	RECALL (MAX = 30)	RECOGNITION (MAX = 24)
Warm	18.00	18.57
Cold	12.00	16.44
Cold Decrement	6.00	2.13
P	< .01	= .052

C. The Pipe Puzzle

Since the pipe puzzle is a two-man task, no data are available for the two subjects (one in each group) whose partner dropped out of the experiment. Time to assemble is available in both conditions for six dive pairs. One pair failed to complete disassembly in the time available in the cold condition giving six disassembly times for the warm condition and five for the cold condition. Mean times are given in Table II-5. When warm and cold times were compared using the Mann Whitney Test, times proved to be significantly longer in cold water for both assembly ($U = 7$, $N_1 = N_2 = 6$, $p < .05$, 1 Tail) and for disassembly ($U = 5$, $N_1 = 6$, $N_2 = 5$, $p < .05$, 1 Tail). Since the task involves a great deal of manipulation of a type that both Bowen (1968) and Stang and Wiener (1970) have shown to be impaired by cold, such a drop in efficiency would be expected.

D. Vigilance

Performance on this task was not affected by cold. Subjects detected 77.2% of the signals in the warm condition and 74.1% in the cold, with seven subjects being more inefficient in warm water and seven more efficient in cold.

TABLE II-5
MEAN PHASE PIPE PUZZLE COMPLETION TIMES FOR
THE WARM AND COLD EXPOSURES

Condition	MEAN Assembly Time (Min)	MEAN Disassembly Time (Min)	TOTAL
Warm	21.8	9.5	31.3
Cold	26.0	11.4	37.4
Cold	4.2 $p < .05$	1.9 $p < .05$	6.1

E. Heartrate

Average heartrates during all seven phases of the experimental runs were virtually identical for the warm and cold exposures. Only complete data obtained during both exposures for each subject are reported. These values, reported in Table II-6, varied little throughout the exposures. This suggests low physiologic work rates during all phases. The addition of the vigilance task apparently prevented the rise in work rates during the assembly and disassembly over non-active phases usually observed (Weltman and Egstrom, et al, 1971).

TABLE II-6
PAIRED HEARTRATE DATA DURING COLD AND WARM EXPOSURES
FOR ALL SEVEN PHASES (N = 12)

	Heartrates	
Phase	40.5°F	78.4°F
Strength Test I	104	101
Reasoning Test I	100	96
Assembly	101	104
Disassembly	102	105
Memory Test	95	96
Strength Test II	89	94
Reasoning Test II	90	84

F. Rectal Temperatures

The average rectal temperatures for our subjects during the 78°F. exposure changed very little. The 40°F. exposures produced an overall mean change of -1.3°F. The mean change in rectal temperature for eleven subjects is shown in Figure II-4.

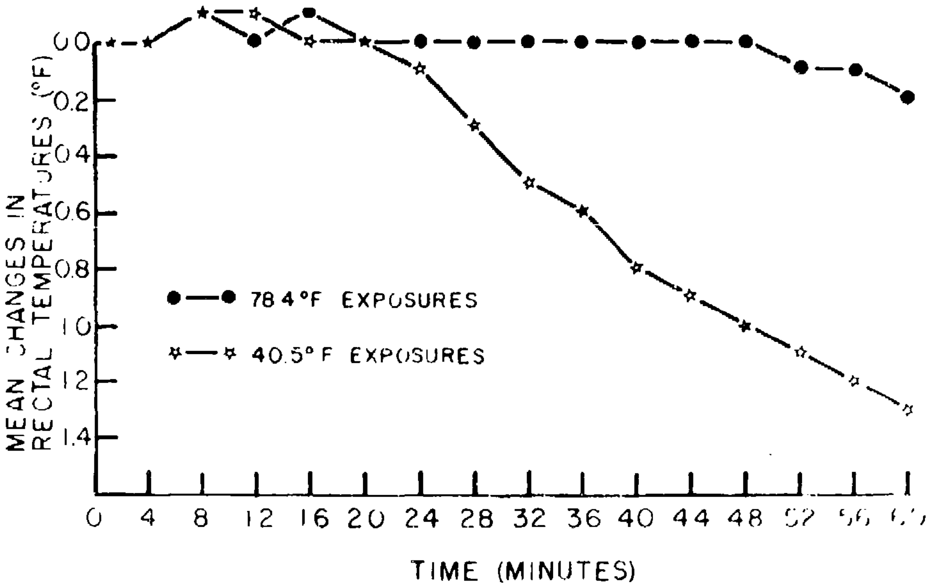

Figure II-4. MEAN CHANGE IN RECTAL TEMPERATURES FOR THE HOUR EXPOSURES IN WARM AND COLD WATER (N = 11)

DISCUSSION

The most striking feature of the results is that despite a mean drop in rectal temperature of 1.3°F., there was no evidence whatsoever of a decrement in reasoning ability, reaction time, or vigilance. This suggests that there is no general loss in cognitive efficiency, and that the effects of cold on performance are peripheral, rather than central in nature. On this hypothesis, cold will affect the diver's ability to respond by making his hands stiff and his fingers numb. It may reduce his level of motivation by making him uncomfortable, and his discomfort may in turn distract him from the task in hand; but provided he is sufficiently well motivated, his capacity for attending and thinking will be unimpaired.

To what extent is this hypothesis consistent with the existing data? Considering first the present study, the impairment in performance on the puzzle presents no problem, since the task requires considerable manipulation and would hence be affected by the decrement in manual dexterity that would certainly be expected in 40°F. water (Bowen, 1968). The impairment in retention might seem to present more of a problem, but at least two "peripheral" explanations are possible. The first might argue that given five minutes to study the passage, the cold subject would less likely concentrate on the task and more likely think about how cold he was and how much longer before he could get out. On this interpretation, a learning task which ensured that the subject was devoting his full attention to the task would eliminate the decrement. It might at first sight seem that the absence of an impairment in vigilance suggests that cold does not influence attention. Unfortunately, the position is complicated by the decrement in performance on the simultaneously performed pipe puzzle task. While the simplest explanation would be to assume that the impairment is due to reduced manual dexterity, it is at least possible that (1) the subject's attentional capacity is reduced, and (2) that it is devoted primarily to maintaining performance on the vigilance task. Assumption (1) seems unlikely in the light of performance on the reasoning task, while assumption (2) does not fit in with the keen competitive interest that subjects took in completion times on the pipe puzzle, compared with a relative disinterest in their vigilance scores. It would however be wise to repeat this study using cognitive tests for both the central and peripheral tasks in order to test the division of attention hypothesis more rigorously.

A second interpretation relies on the concept of state-dependent learning. There is good evidence that recall is optimal when it occurs in the same environment as the original learning. Thus, Greenspoon and Ranyard (1957) showed that a list of items learned in a brightly lit, noisy, smelly, and uncomfortable environment are better recalled in that environment than in a dimly lit, quiet, odorless, and comfortable environment - and _vice versa_. A similar effect is found if subjective environment is changed by means of drugs such as nitrous oxide (Steinberg & Summerfield, 1957) or alcohol (Goodwin, Powell, Bremer, Hoine, and Stern, 1969). What is learned when drunk is best recalled when drunk. On this interpretation, subsequent recall is impaired because the environment is so different from that in which the learning occurred, the environmental difference being particularly great in the cold-water condition. On this hypothesis, no decrement should occur if retention is tested before leaving the water. It is of course also possible that the decrement could be central in nature; but in view of the negative results from the other cognitive tasks, it would seem advisable to begin by testing the peripheral hypotheses.

The present results then provide no unequivocal evidence of anything other than a peripheral effect of cold on human performance. Examination of the literature provides very little additional evidence. Bowen and Pepler (1967) found an effect of cold on arithmetic performance, which they attribute to the subject's difficulty in writing his answers. An increase in errors on both a symbol-processing task and a test involving memory for the times on a series of clock faces was also found, which was in both cases entirely attributable to the difference between wet and dry performance rather than to a cold effect. The only trend which appeared to show a genuine cold effect was for omission of items from a problem solving task. These increased from 2.5% at 72° F. to 5.0% at 47° F.; but with data from only five subjects, it would be unwise to place much weight on this relatively small effect. Stang and Wiener (1970) found a decrement in reaction time which could be attributed to cognitive impairment due to cold; but in view of the conflicting evidence from Teichner (1954) and from our own study, an interpretation in terms of impaired manual dexterity seems more likely. Finally, the effect of cold on time estimation observed by Baddeley (1966) is hard to interpret since we know virtually nothing of the processes, central or peripheral, on which time estimation is based.

<u>Conclusions and Recommendations</u>

A. Exposure to cold water does not uniformly impair cognitive performance in complex work tasks. In fact, some aspects of performance, such as reaction time, peripheral vigilance, and reasoning appear highly resistant to cold effects.

B. The diver's ability to remember written material learned underwater is decreased for cold exposure. The cause is not clear, but present evidence points to a peripheral effect.

C. A more comprehensive test of the working hypothesis that cognitive performance is resistant to cold should be performed. In addition, this test should attempt to determine whether the observed decrement in retention is due to central or peripheral causes.

III. MEMORY UNDERWATER

INTRODUCTION

One of the many tasks demanded of a working diver is that of an underwater observer. Despite the development of underwater television, the flexibility and mobility of a skilled diver makes him valuable for a wide variety of observational tasks, ranging from the inspection of oil-well heads to the observation of the behavior of fish at the mouth of a trawl net. If the diver's full potential is to be used, he must not only be able to observe, but must subsequently be able to remember what he has seen when he is debriefed on the surface.

The study described in the previous section of this report demonstrated that the temperature of the water in which a diver learns material has a significant effect on his subsequent ability to report that material on the surface. A study of Davis, Osborne, Baddeley, and Graham (in preparation) studied the learning and recall of sequences of unrelated words at depths of 10 and 100 feet in the open sea. They found no reliable effect of depth on either the long-term or short-term memory components of the task despite clear evidence of a narcosis decrement on other tasks in the study. Since both learning and recall occurred underwater, however, there was no indication of whether subsequent recall on the surface would have been impaired. Neither study answered the basic question of how well a diver can be expected to remember what he saw underwater, when he is debriefed on the surface. The present experiment attempted to do so by comparing the retention of material learned on the surface and at depths of 15 and 110 feet in the open sea.

METHOD

Memory Test

The memory test was the same one described in the previous chapter - descriptive passages arranged according to the method suggested by Friedman (1972). Test measures were again recall and recognition. Three such passages on topics of interest to divers were produced - namely, underwater game, wrecks, and underwater jobs. They are given in Appendix A, together with one of recognition tests used with each.

Design

Three groups of subjects were each given a practice test prior to the experimental test. In all cases, the test comprised the underwater game passage and was administered on dry land. The experimental test comprised either the underwater wrecks or the underwater jobs passage (an approximately equal number of each being used in each group). One group of divers (N = 13) learned the second passage at a depth of 110 feet in the open sea; a second group (N = 15) learned it at a depth of 15-20 feet in the open sea, while a third group (N = 14) learned it on dry land.

Procedure

During the practice run the subjects spent five minutes memorizing their passage, then three minutes adding columns of five two-digit numbers. Immediately afterwards, they took the recall test, followed by the recognition test. Subjects were given as much time as they wanted to complete the tests.

The deep tests were carried out in Mission Bay, San Diego, at a depth of 110 feet, and the shallow tests at a depth of 14 feet in either Mission Bay or off Catalina Island, California. In all cases, diving was from a launch. Subjects dived in groups of up to six. They were directed by a single experimenter who timed memorization and addition using a diving watch. The experimenter signalled the start and end of each test by tapping the subject on the arm.

The surface tests were conducted on the deck of the launch at the same time as the underwater tests. Thirty minutes after completion of the arithmetic portion period, all subjects performed an additional three minutes of arithmetic and then took the recall and recognition tests on the deck of the launch.

The passages were typed on paper which was bound to a formica board with transparent plastic-adhesive sheeting. The arithmetic was similarly presented with the exception that a strip of waterproof mat tape was laid along the answer line. This allowed subjects to write their answers in pencil and meant that the test could be re-used again after replacing the strip of tape.

Subjects

All 42 subjects were trained scuba divers who were participating in either a National Association of Underwater Instructors advanced training course or in a UCLA Diving Club boat dive.

RESULTS

Table III-1 shows the mean recall scores for the practice and test conditions. Table III-2 presents similar data for the recognition test. Statistical analysis of the practice test scores indicated that the deep group was statistically worse than the surface control group on recognition (Mann Whitney test, $U = 52.5$, $N_1 = 13$, $N_2 = 14$, $p < .05$, 1 tail). Each subject's practice scores was therefore used as a baseline. His test scores were subtracted from practice scores to provide a test condition decrement for each subject. The mean practice less test scores for recall and recognition are also presented in Tables III-1 and III-2 respectively.

Statistical comparisons of the different scores (Practice minus test) were made using the Mann Whitney test The recall decrement in the shallow condition over the surface control proved to be statistically significant ($U = 59$, $N_1 = 15$, $N_2 = 14$, $p < .05$, 2 tail). The increased decrement seen in the deep condition was not significantly different from the shallow condition ($U = 89.5$, $N_1 = 13$, $N_2 = 15$, $p > .1$). Indeed, although the deep condition showed the greatest mean decrement, its variability was such that it was not significantly different from the surface control ($U = 65.5$, $N_1 = 13$, $N_2 = 14$, $p > .1$).

Statistical analysis of the recognition scores show that none of the differences between conditions approached statistical significance ($p > .1$ in all cases).

TABLE III-1
MEAN RECALL SCORES

Condition	Mean Recall Scores		
	Practice	Test	Practice less Test
Surface (N = 14)	21.8	17.8	4.0
Shallow (N = 15)	21.7	13.8	7.9
Deep (N = 13)	18.2	9.7	8.5

TABLE III-2
MEAN RECOGNITION SCORES

Condition	Mean Recognition Scores		
	Practice	Test	Practice less Test
Surface (N = 14)	20.6	18.5	2.1
Shallow (N = 15)	19.9	16.8	3.1
Deep (N = 13)	18.2	17.3	1.9

DISCUSSION

These results suggest that material learned underwater is not well recalled on the surface, although subsequent recognition is not reliably impaired. The absence of a recognition decrement suggests that the impairment is not due to a difference in degree of learning between the two conditions. This suggests retrieval difficulty as the most likely explanation. There is a good deal of evidence that learning may be state-dependent, i.e. that adequate recall is impaired if the stimulus situation at recall differs from that experienced during learning. The difference may be in terms of the external surroundings or in terms of the subject's internal state resulting from the administration of a drug. Thus, Greenspoon and Ranyard (1957) had subjects learn a list of paired-associated nonsense syllables either sitting in a quiet, dim, odorless room or standing in a noisy, bright, smelly room. Subsequent recall was tested in either the same or the opposite environment and was found to be considerably better when the recall and learning environments were identical. Goodwin, Powell, Bremer, and Hoine (1969) showed a similar state-dependent effect with alcohol. Subjects who learned the material when drunk recalled it better drunk then sober. As with our results, no decrement occurred when a recognition test was used, suggesting that the defect was probably one of retrieval rather than storage.

A second notable feature of our results is the absence of difference between the deep and shallow conditions. A depth of 110 feet should be enough to produce mild nitrogen narcosis, and arithmetic scores suggest that narcosis was present. A total of 17 subjects performed the test twice, once in the deep and once in the shallow condition, with approximately half being tested in each of the two orders. There was a significant tendency for subjects to make more errors at depth ($p < .01$, Sign Test) and to do fewer correct sums ($T = 26.5$, $N = 16$, $p < .05$, 2 tail, Wilcoxon Test). The absence of a decrement in either recall or recognition suggests that memory is much less sensitive to narcosis than arithmetic, reasoning, or manual dexterity--all of which show a clear decrement when tested at 100 feet in the open sea (Baddeley, de Figueredo, Hawkswell, Curtis, and Williams, 1968; Davies, Osborne, Baddeley, and Graham, 1972). Assuming the underwater memory decrement to be a state-dependent effect, this suggests that the degree of change in the subject's internal state accompanying mild nitrogen narcosis is small compared with the difference in the subject's external environment between the underwater learning situation and the surface recall situation.

Conclusions and Recommendations

A. There is likely a significant decrement in recall on the surface of written material learned underwater. This decrement may increase with depth; and it may extend to recognition of learned material as well, even though these effects are apparently less and exhibit far greater individual differences.

B. Future experimentation should determine whether this effect holds for non-written material as well, whether it is equally true for material learned on the surface and recalled underwater, what is its relation to narcosis and other stresses, and what are the concommitants of the individual differences.

C. From a practical standpoint, it appears unwise to rely directly on the diver's memory in gathering underwater information. Structured debriefings should be used rather than free recall, and the diver should be supplied with a means of on-site data recording.

IV. DRY AND WET TRAINING

INTRODUCTION

The specific task training that a diver receives prior to final performance of the task underwater most often consists of dry-land instruction and practice trials. The basic advantages of conducting task training on dry-land are 1) ease in communicating instructions, 2) administration of corrective feedback, and 3) the lower level of support required to perform the training. Considering the highly specific demands imposed by the underwater environment, i.e. loss of traction, impairment of sensory functions, narcosis, restriction of the visual field, etc., the value of such training can be questioned. For example, can the diver transfer dry-land, task-oriented cognitive and motor behavior to the same task underwater? Might the dry-land, task-oriented behavior interfere with the development of efficient underwater methods? Such questions prompted a pilot study at UCLA in order to ascertain the differences, if any, in performance on a complex underwater task between divers who trained for the task on dry-land and divers who trained for the task underwater.

METHOD

Diving Task

The task used was the UCLA Pipe Puzzle Construction Task, as described in Chapter II.

Performance Data

The principal indicator of work output used in this study was construction task phase completion times. To verify that changes in completion times did not occur at the expense of the quality of the work performed, errors in construction and procedure were also recorded.

A. Construction Task Phase Completion Times

Phase completion times were recorded by the experimenters, who were continuously observing the subjects through the observation ports in the diving tank and through verbal communication with the subjects. To insure standardization and ease of identification of the completion of task phases, the divers were instructed to complete certain sub-tasks before proceeding to the next. For example, the completion of torquing of all flange bolts was defined as the end of assembly. The divers were instructed, therefore, not to proceed with the connection of the air supply until torquing had been completed. Similarly, dewatering and depressurization of both sides of the pipe puzzle had to be completed before disassembly was started.

B. Construction and Procedural Errors

Errors made during the assembly, dewatering, and disassembly phases were recorded by the experimenter. A construction error that was not immediately corrected was defined as a mistake in the assembly of the pipe puzzle components. A misjudgement which resulted in a delay of completion due to the correction, such as improper placement of a gasket, was also recorded. A procedural error was further defined as a variation from the prescribed series of sub-tasks, such as the failure to complete the torquing of all bolts on joints or the pipe puzzle.

Subjects

The eight subjects used for this study were students from a local commercial diving school. While attending the school, they made daily dives with various types of diving equipment, including Kirby-Morgan band masks, which were used in this study. The physical data for the group is presented in table IV-1.

TABLE IV-1
PHYSICAL DATA FOR SUBJECT GROUP PARTICIPATING
IN THE TRAINING EXPERIMENT (N = 8)

	Mean	Range
Age	22 years	19 to 26
Height	5'11"	5'6" to 6'3"
Weight	167 pounds	140 to 185

Locale

Work conducted in this study was performed at the UCLA Underwater Research Facility. The training runs for the teams that were trained in the water and all of the experimental exposures were conducted in the diving tank within the facility complex. The dry-land training runs were conducted on a level area adjoining the tank. The water conditions in the tank were ideal. The temperature was 75° F., visibility was perfect, and the tank depth was 16 feet.

Equipment

The subjects wore 3/16-inch wet suits, booties, fins, weight belts, and Kirby-Morgan Band Masks. The masks were supplied through umbilicals and were equipped with communication systems that permitted the divers to converse with the experimenters but not with each other.

Experimental Protocol

The eight subjects were given verbal instructions and a dry-land task demonstration as a group. The group was then divided into four two-man teams and assigned to either the dry-land group or the water group. The teams were urged to thoroughly discuss their plans and decide upon task assignments. The teams were then given an individual training run on the task. Verbal communication was denied for both dry-land and water-trained divers. During these runs, errors were pointed out to the subjects as they were made. Additionally, all questions asked by the subjects were answered at all times except during the experimental run. Upon completion of the training runs, the teams were again urged to discuss the task. When the training phase had been completed, the teams were given their experimental runs.

RESULTS

A. Construction Task Phase Completion Times

Completion times for the three task phases and total completion times are presented in table IV-2. Figure IV-1 represents mean phase completion times. These results show that performance was consistently better during all phases by the water-trained teams. The differences indicated represent 24, 35, and 21 percent decreases in time during the assembly, dewatering, and disassembly phases respectively. The mean total completion time for the water-trained teams was 25 per cent faster

TABLE IV-2
PHASE COMPLETION TIMES FOR THE TEAMS TRAINED ON DRY-LAND AND THOSE TRAINED IN THE WATER

	Completion Times (Minutes)			
Group	Assembly	Dewatering	Disassembly	Total
Dry-land trained				
Team 1	21	10	12	43
Team 2	21	4	11	36
Mean	21	7	11.5	39.5
Water trained				
Team 3	15	6	9	30
Team 4	17	3	9	29
Mean	16	4.5	9	29.5

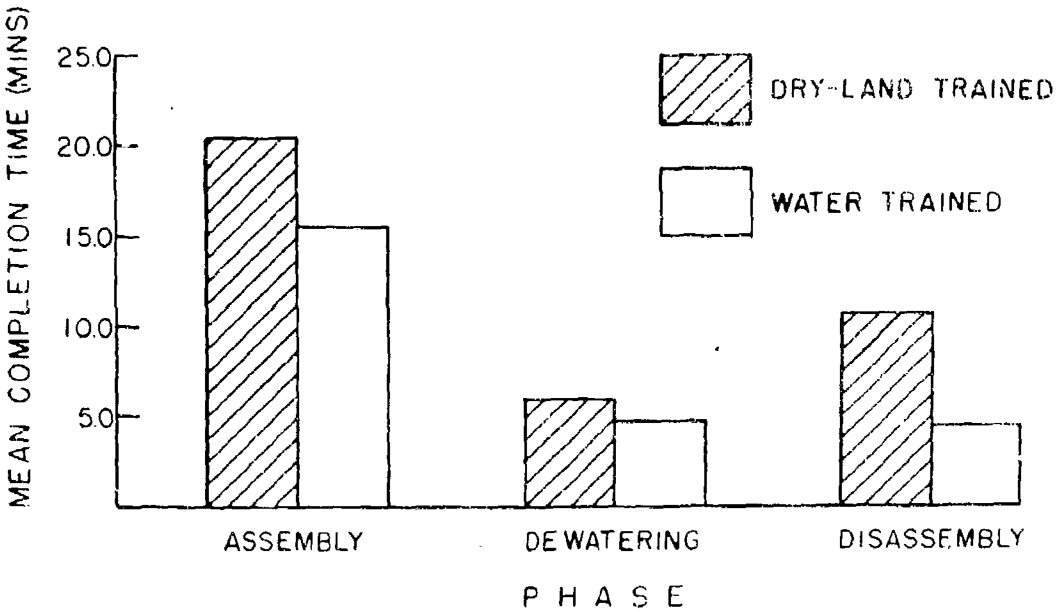

Figure IV-1. MEAN PHASE COMPLETION TIMES FOR THE DRY-LAND AND WATER-TRAINED GROUPS

B. Construction and Procedural Errors

Performance on the construction task during the experimental runs was virtually identical for the two groups. Both dry-land trained teams made one construction error. One of the water-trained teams also made one construction error. All three errors involved improper placement or torquing of the bolts. The decreases in phase-completion times for the water-trained teams over the land-trained teams were apparently not obtained at the expense of the quality of work performed.

Conclusions and Recommendations

A. Results of this small pilot study indicate that training on dry land is not as effective as wet training in preparing divers for complex task performance.

B. A more complete investigation is required to determine the relative efficiency of the two techniques for several types of task requirements.

C. It appears worthwhile to develop recommendations for deriving an optimum mix of dry and wet training for the types of jobs most frequently encountered underwater.

V. PHYSIOLOGICAL CORRELATES OF COMPLEX TASK PERFORMANCE IN COLD WATER BREATHING HELIUM-OXYGEN

INTRODUCTION

Body heat loss is a critical problem for the working diver. This is primarily due to the high thermal conductivity of water as compared to that of air. The need to substitute helium for nitrogen in the diver's breathing medium to prevent narcotic effects introduces a further change from the thermodynamic environment which the body is normally subjected to. When the diver's external thermal protection is provided by a wetsuit, this substitution is reflected in the change in respiratory heat loss.

The substitution of helium for nitrogen in the breathing mixture, in addition, has been shown to alter the respiratory response to exercise (Murphy, et al., 1969 and Nottie and Tenney, 1970). The change is primarily manifested in increased minute volume. It is possible that this or other mechanisms might modify the diver's physiologic state or his ability to perform useful work. Thus, the purpose of this experiment is to determine the effects of an artificial breathing mixture of helium and oxygen on the diver's physiologic state and performance. A group of divers were examined while performing an underwater construction task breathing air and again breathing a 20% oxygen - 80% helium mixture. Cold water was used to magnify the thermal effects of the breathing media.

METHOD

The diver work task utilized for this experiment was the UCLA underwater construction task, as described in Chapter II.

In addition to the construction task, a short set of diving physics problems was presented to the divers before the construction task, and a second set was presented after the task. The purpose of these problems was to provide an indicator of cognitive performance. An example of the type of questions asked is: "Calculate the volume of air in a sealed balloon at the surface if it was filled with two cubic feet of air at a depth of 66 feet " These questions were contained, along with construction task instructions, on a plastic tablet given to each diver.

Performance Data

Three performance variables were measured for this study. They were construction task phase completion times, construction and procedural errors, and dive problem correctness.

A. Construction Task Phase Completion Times

Completion times for the three construction task phases and the two dive problem sets were recorded by the divers on their dive tablets. The experimenters recorded the completion times. The times recorded by the divers were later checked for correctness.

B. Construction and Procedural Errors

Construction errors were defined as errors in assembly that were not immediately corrected or that resulted in a delay in completion of an operation. Improper placement of the rubber gaskets used for sealing the structure is an example of such an error. Procedural errors were defined as a deviation or omission from the prescribed order of operations. Such an error would be the incomplete torquing of all nuts on a flange.

C. Dive Problem Correctness

Upon completion of an experimental run, the divers' answers to the pre-problems, the problem set presented before the assembly phase, the post-problems, and the problem set presented after disassembly were recorded by the experimenters. They were later checked for correctness.

Physiological Recording

Heartrate, respiratory minute volume, and rectal temperatures were monitored during the experimental run. Heartrate and respiratory minute volume were used as indicators of physiological workload, and rectal temperature gave an indication of the divers' thermal state.

A. Heartrate

Skin electrodes were placed on both sides of the torso at about the fifth rib, lateral to the pectoralis muscle. This arrangement minimized extraneous EMG signals and presented large, distinct QRS complexes. The electrodes were connected via cables attached to the umbilicals to a multichannel strip chart recorder for continuous recording. Heartrates were later obtained by counting QRS complexes for a given time interval. Dual channels allowed for simultaneous recording of both divers' heartrate.

B. Respiratory Minute Volume

A laminar flow meter utilizing a differential pressure transducer is incorporated into the gas supply lines. The transducer has an output which is proportional to the flow through the meter. This signal is integrated by an operational amplifier which is automatically rezeroed every 60 seconds. The output of the amplifier at the time of rezeroing is therefore proportional to the volume of gas that has traversed the flow meter during the previous 60 seconds. This output is recorded by a strip chart recorder and is later reduced by hand to minute volume values.

C. Rectal Temperature

Rectal temperatures were obtained from thermistor probes which were inserted approximately four inches into the rectum. The probes are small, bead thermistors encapsulated in an epoxy shaft.

The thermistor is incorporated into a resistance bridge network.

The electrical resistence of the thermistor is proportional to its temperature; therefore, the voltage across the bridge network is also proportional to temperature. The bridge voltage is appropriately amplified and recorded by the strip chart recorder.

Subjects

Twelve subjects were used in this study. Six were students in a local commercial diving school, four were members of the Los Angeles County Sheriff's Search and Rescue Team, and two were college professors. All were certified divers. The average diving experience for the group was 5 years. The physical data for the subject group is shown in table V-1.

TABLE V-1
SUBJECT PHYSICAL DATA (N - 12)

	Mean	Range
Age	30 years	21 - 42
Height	5' 11"	5' 8" - 6' 4"
Weight	181 pounds	146 - 236

Locale

All experimentation for this study was carried out at the UCLA Underwater Research Facility. The average water temperature was 42° F. ranging from 41° - 44° F. Water clarity was ideal The depth was 16 feet.

Diving Equipment

The subjects wore 3/16-inch, neoprene wetsuits, hooded vests, gloves, and booties for thermal protection. Kirby-Morgan band masks were used to deliver the breathing mixtures. The masks also provided thermal protection for the face. Additionally, the subjects wore fins and were weighted with approximately 30-pound weight belts. The communication system incorporated in the masks allowed the divers to verbally communicate with the experimenters, but not with each other. Breathing gases were surface supplied from a premixed bottled gas supply.

Procedure

Six two-man teams were formed from the subject group. Each team participated in a dry-land training session and in two experimental trials. One experimental trial was performed using air as the breathing gas. The other was performed using an 80-percent helium - 20-percent oxygen mixture as the breathing gas.

The training session consisted of verbal instructions and a construction task demonstration by the experimenters. This was followed by a complete dry-land construction exercise by the subject team. The subjects were then given instruction on the solution methods of the pre and post-problems. All questions pertaining to the construction task or to the dive problems were answered to the subjects' satisfaction during the training session.

RESULTS

A. Heartrate

Heartrate during the helium-oxygen exposures were slightly higher than during the air exposures. The differences, as shown in Table V-2, increased somewhat during the runs.

TABLE V-2
HEARTRATES FOR THE GROUP DURING THE FIVE PHASES FOR BOTH THE AIR AND HELIUM-OXYGEN EXPOSURES (N = 12)

	Heartrates		
Phase	Air	Heliox	Difference
Pre Problems	105.3	106.5	0.8
Assembly	110.4	111.3	0.9
Dewatering	104.0	108.7	4.7
Disassembly	108.8	112.1	3.3
Post Problems	98.8	104.4	5.6

B. Minute Volume

Minute volumes, as depicted in Table V-3, were substantially higher during the helium-oxygen exposures. The difference became statistically significant (Wilcoxon signed rank test) during the post-problem phase. The values reported are depth corrected to give the volume of gas ventilated by the lungs at depth.

TABLE V-3

MINUTE VOLUMES IN LITERS/MINUTE FOR THE GROUP DURING THE FIVE PHASES FOR BOTH THE AIR AND HELIUM-OXYGEN EXPOSURES (N = 12)

	Minute Volumes (liters/minute)		
Phase	Air	Heliox	Difference
Pre Problems	21.2	24.2	3.0
Assembly	26.6	30.1	3.5
Dewater	29.1	32.5	3.4
Disassembly	31.7	35.0	3.3
Post Problems	27 8	33.6	5.8 $p < .01$

C. Rectal Temperatures

Rectal temperatures for eleven of the twelve subjects is plotted to the nearest tenth degree Fahrenheit in Figure V-1. The twelfth was not obtained during an air run; it was therefore also excluded from the helium-oxygen average. Although the difference in the average rectal temperature reached 0.4° F. at the 45-minute point, it was not statistically significant by the Wilcoxon signed rank test.

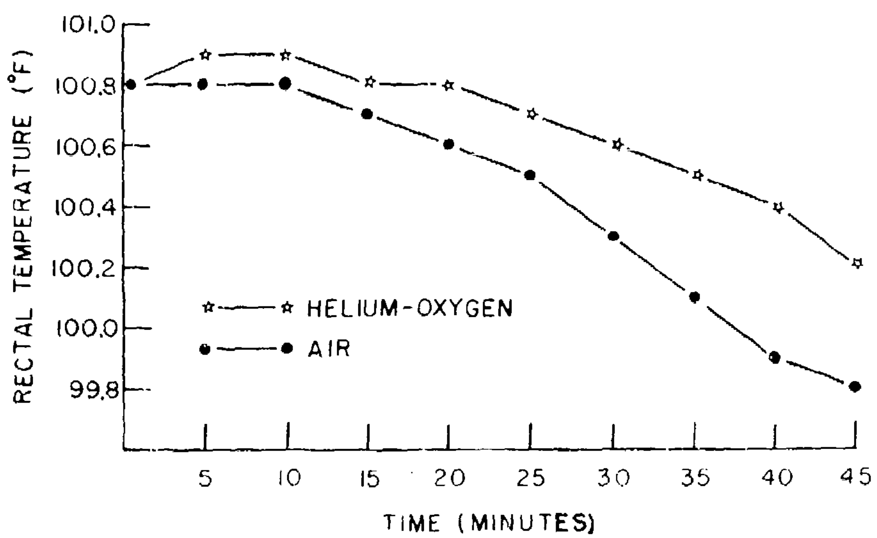

Figure V-1. AVERAGE RECTAL TEMPERATURES FOR THE GROUP DURING THE AIR AND HELIUM-OXYGEN EXPOSURES (N = 11)

D. Construction Task Phase Completion Times

Phase completion times were virtually identical for the two exposures. The averages for the six teams are presented in Table V-4. The completion times for both series are somewhat slower than we have previously observed for subjects in similar exposures (Weltman and Egstrom, et al., 1971).

TABLE V-4
CONSTRUCTION TASK PHASE COMPLETION TIMES IN MINUTES FOR THE SIX TEAMS DURING THE AIR AND HELIUM-OXYGEN EXPOSURES

	Completion Times (mins.)	
Phase	Air	Heliox
Pre Problems	4.5	4.8
Assembly	28.8	29.7
Dewatering	7.2	6.0
Disassembly	16.0	15.7
Post Problems	4.6	5.0
Total	61.1	61.2

E. Construction and Procedural Errors

The teams made relatively few errors during the experimental runs. They committed a total of six errors while breathing air and five errors while breathing the helium-oxygen mixture. This low error rate was probably in part due to the relatively slow completion times, particularly during the assembly phase.

F. Dive Problem Performance

The percentage of correct dive problems were relatively the same for both series of exposures. The divers answered 56 percent and 55 percent of the pre-problems during the air and helium-oxygen exposures respectively. Their performance fell to 44 percent and 50 percent during the post-problems. Neither air to helium-oxygen or pre-problem to post-problem comparisons produced statistically significant differences (Wilcoxon signed rank test).

DISCUSSION

The results of this study indicate that divers are able to work equally well whether breathing air or breathing a helium-oxygen mixture.

All of the performance indicators were virtually identical. The apparent physiologic cost of this work was slightly higher for the helium-oxygen mixture. Heartrates and minute volumes were both increased, and rectal temperatures remained higher while breathing the helium-oxygen mixture.

The respiratory heat loss equation was employed to predict the thermal state of our subject population after an exposure time of one hour. Webb and Annis (1966) have found that the heat lost in humidifying various dry-inspired gas mixtures to be the same. The difference in heat loss was therefore solely the result of warming the inspired gas. The solution of this term in the equation yielded a prediction of slightly smaller heat losses with the helium-oxygen mixture. Thus, in addition to the slightly higher physiologic work rate during the helium-oxygen exposures, resulted in the maintenance of higher rectal temperatures.

VI. NAVY-MAKAI DIVING OPERATIONS

INTRODUCTION

The UCLA Underwater Research Team participated in the Navy-Makai Diving operations conducted at the Makai Range, Hawaii, during November and December, 1971. These operations involved a 200-foot dive of the Aegir submersible work station, which was accomplished, and a 520-foot dive, which was not.

The UCLA contribution to these operations was a study of diver performance in underwater construction tasks, conducted as part of the ocean-floor experimental program. This study is described in detail in a forthcoming ONR report. A brief summary is included here to complete the present record of the year's activities.

STUDY PLAN

The perceptual motor aspects of work performance were measured by a specially prepared version of the UCLA "pipe-puzzle" construction task, which requires a broad range of diving skills for successful completion. Cognitive aspects of underwater work were sampled by a paper-and-pencil test involving post-work recall of items memorized underwater. In addition, heart rate data were obtained to estimate the energy cost of work accomplishment.

All of the above measures have been previously applied in other studies by the UCLA team. Experience has shown that they are sensitive indicators of performance. These measures have also served to accumulate a useful store of related data. The study utilized two teams of two divers each from the participating group. They were trained in the various tasks, and baseline data were obtained in relatively shallow water at Point Magu and the Makai Range pier. Test data were obtained for the same tasks conducted at 200 feet and compared with the baseline results. Originally, the plan called for a similar test at 520 feet.

OBJECTIVES

The objectives were threefold; namely:

1) To help answer the question: Does immediate or prolonged deep exposure adversely effect the ability of divers to accomplish complex ocean work?

2) To evaluate the effectiveness of remote work measurement techniques under realistic and rigourous diving conditions.

3) To evaluate the effectiveness of the deep station concept as a means of performing underwater biotechnical research.

RESULTS

Cancellation of the Makai operation after the 200-foot dive precluded the collection of data under the more interesting 520-foot condition. Nevertheless, the information obtained prior to cancellation was sufficient to cover some of the study objectives, considering that many of the critical factors anticipated at 520 feet (saturation, isolation, living conditions, surface support, poor communication, diving equipment, water temperature, and clarity, etc.) were also present in the 200-foot exposure.

Subtask completion times for the pipe puzzle and apparent physiological work levels were the same at 200 feet as during the shallow baseline runs. Regarding cognitive performance, the present results confirmed previous findings that there is an adverse underwater effect on memory. It appeared tentatively that this effect was greater at 200 feet than at shallow depths, suggesting that the effect is sensitive to stress and may be a factor in deeper work operations.

In the study, remote work measurement depended primarily on reporting by the divers themselves. Observation by the investigators through TV monitoring and video recording was primarily for backup. This procedure yielded excellent results; no data were lost due to diver oversight or error. Factors important to its success were: (1) careful indoctrination of the diver group, (2) simple data sheets and separately marked packets for each run, and (3) adequate practice prior to the test trial.

Finally, no undue problems were encountered with logistics or with scheduling aside from the final test delay. Support personnel and divers were supercooperative, access to the experiment was perfectly adequate. From the scientific standpoint, the greatest disadvantage was the small number of subjects. This was compensated for partly by the opportunity to make repeated baseline measurements, so that the ultimate test results could be evaluated with some confidence.

Conclusions and Recommendations

A. Complex construction tasks can be accomplished as effectively from a 200 foot deep work station as at shallow ocean deep depths by experienced and competent divers.

B. Remote measurement techniques previously developed at UCLA proved successful for data acquisition from the deep work station.

C. The Navy-Makai program was a satisfactory means of acquiring underwater performance data under conditions generally not available to the academic community. Scientific participation on future "real-life" programs is recommended. However, prior interchanges among the investigators themselves would help maximize the efficiency of data gathering.

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Appendix A

Memory Passages, Sample Recognition Tests,

Sample Arithmetic Test

Underwater Game around Snake Island

Snake Island has six major types of game. The Grey Lobster is found in caves. It is delicious barbecued, and there is a bag limit of three. The Fluted Scallop has a bag limit of six. It is found in tide pools and is best when fried. The Striped Sole is found in shallow bays; there is a bag limit of five. It is best cooked by steaming. The Golden Abalone is found on the underwater cliffs. The bag limit is four and the best method of cooking is by stewing. The Speckled Bass is found in open water. The bag limit is seven and baking is the best method of cooking it. The Horned Crab has a bag limit of two. It is usually found around pier pilings and makes a delicious soup.

You must remember to learn the characteristic of each animal, since in recognition testing the crab, for instance, might be referred to as either "the crab" or as "the horned creature," the abalone as the "golden creature" and so forth.

Name ______________________ Condition ______________________

Answer the following true-false questions about the reading. Circle the correct letter in the column on the right.

1.	The horned creature is a crab.	1.	T	F
2.	The striped creature is best stewed.	2.	T	F
3.	The lobster lives in caves.	3.	T	F
4.	The bag limit of the golden creature is 3.	4.	T	F
5.	The golden creature is an abalone	5.	T	F
6.	The bag limit on bass is 7.	6.	T	F
7.	The abalone are found in tide pools.	7.	T	F
8.	The lobster are best barbecued.	8.	T	F
9.	The fluted creatures are found around pier pilings.	9.	T	F
10.	The bag limit on the fluted creatures is 6.	10.	T	F
11.	The golden creatures live in open water.	11.	T	F
12.	The bag limit on the striped creatures is 5.	12.	T	F
13.	The crabs live around pier pilings.	13.	T	F
14.	The bag limit on bass is 2.	14.	T	F
15.	The bag limit on crabs is 6.	15.	T	F
16.	The bag limit on the grey creature is 2.	16.	T	F
17.	The bass are best baked.	17.	T	F
18.	The grey creatures are found on underwater cliffs.	18.	T	F
19.	The scallops are best fried.	19.	T	F
20.	The bass are found in shallow bays.	20.	T	F
21.	The sole are striped.	21.	T	F
22.	The crabs make good soup.	22.	T	F
23.	The speckled creatures are best fried.	23.	T	F
24.	The fluted creatures live in caves.	24.	T	F

Underwater Work Program

Inspect the harbor wall at San Roberto for the San Roberto Harbor Board (estimated diving time, 4 hours). Finish welding job on the oil rig at Martha Head for the Mogul Oil Company (estimated diving time, 1 hour). Find and salvage an outboard motor at Maryport for the Maryport Water Ski Club (estimated diving time 2 hours). Collect rock samples from Black Bay for the Rio Plata Mining Company (estimated diving time 6 hours). Rivetting job on the bridge at Evans Lagoon for the State Department of Highways (estimated time 3 hours). Construction of a fish cage at Point Juan for the Marine Biology Laboratory (estimated time 5 hours).

Answer the following true-false questions about the reading. Circle the correct letter in the column on the right.

1.	The rivetting is to be done on a bridge.	1.	T	F
2.	The oil rig job should take 5 hours.	2.	T	F
3.	The rock samples will come from Black Bay.	3.	T	F
4.	The job for the Rio Plata Co. is at Martha Head.	4.	T	F
5.	The salvage job is for the Water Ski Club.	5.	T	F
6.	The building job is for the Marine Biology Lab.	6.	T	F
7.	The building job is at Evans Lagoon.	7.	T	F
8.	The collecting job should take 6 hours.	8.	T	F
9.	The job on the harbor wall should take 3 hours.	9.	T	F
10.	The inspection job is for the Harbor Board.	10.	T	F
11.	The fish cage is to be at Maryport.	11.	T	F
12.	The oil rig is at Martha Head.	12.	T	F
13.	The rivetting job is at Evans Lagoon.	13.	T	F
14.	The inspection job is for the Highways Dept.	14.	T	F
15.	The welding job is for the Harbor Board.	15.	T	F
16.	The rock samples are for the Mogul Oil Co.	16.	T	F
17.	The salvage job should take 2 hours.	17.	T	F
18.	The rock samples are from Evans Lagoon.	18.	T	F
19.	The inspection job should take 4 hours.	19.	T	F
20.	The salvage job is at Martha Head.	20.	T	F
21.	The welding is to be done on the oil rig.	21.	T	F
22.	The rivetting job should take 5 hours.	22.	T	F
23.	The outboard motor job should take 4 hours.	23.	T	F
24.	The harbor wall job is at Maryport.	24.	T	F

Wrecks around Snake Island

There are six wrecks within easy reach of Snake Island. The fishing boat Lucky Lucy lies in a kelp forest at a depth of 10 feet in an area infested with scorpion fish. The submarine Franklin lies on sand at 50 feet in a very cold current. The tramp steamer Ocean Star is at a depth of 40 feet in a canyon scoured by a dangerous rip tide. The cruiser Alaska lies at 20 feet in mud, hence, visibility is always bad. The liner Aquarius is at a depth of 60 feet on a coral reef with many sharks. The tug Mary Ann is at a depth of 30 feet surrounded by eel grass. It is dangerous because it contains many sharp obstructions which can easily cause snagging.

Answer the following true-false questions about the reading. Circle the correct letter in the column on the right.

1.	The name of the submarine is Alaska.	1.	T	F
2.	The tug boat is surrounded by eel grass.	2.	T	F
3.	The Ocean Star lies at a depth of 30 feet.	3.	T	F
4.	The cruiser is in an area of bad visibility.	4.	T	F
5.	The Franklin is in an area infested with sharks.	5.	T	F
6.	The tug is called the Lucky Lucy.	6.	T	F
7.	The liner lies on a coral reef.	7.	T	F
8.	The submarine contains many sharp obstructions.	8.	T	F
9.	The Aquarius lies at a depth of 60 feet.	9.	T	F
10.	The cruiser lies in a kelp forest.	10.	T	F
11.	The tramp steamer lies in a canyon.	11.	T	F
12.	Scorpion fish are a problem near the liner.	12.	T	F
13.	The Alaska lies at 10 feet.	13.	T	F
14.	There is a rip tide where the Ocean Star lies.	14.	T	F
15.	There are a lot of scorpion fish around the Lucky Lucy.	15.	T	F
16.	There is a cold current by the submarine.	16.	T	F
17.	The Franklin lies in mud.	17.	T	F
18.	The tug lies at a depth of 30 feet.	18.	T	F
19.	The Aquarius lies in a canyon.	19.	T	F
20.	The Franklin lies at 50 feet.	20.	T	F
21.	The fishing boat is called the Mary Ann.	21.	T	F
22.	The Alaska lies in a canyon.	22	T	F
23.	The fishing boat lies in a kelp forest.	23	T	F
24.	The cruiser lies at 20 feet.	24	T	F

Name____________________________

Add the following columns of numbers and write your answer in the space provided.

29	86	78	40	19	94	30	18
53	45	87	35	71	18	53	41
27	54	71	66	27	31	26	81
55	24	49	87	76	86	99	83
10	48	16	38	90	15	66	57

28	79	56	36	86	39	29	17
68	10	30	61	65	83	91	20
99	93	21	64	95	69	35	45
91	54	49	11	58	56	44	91
42	12	18	49	23	78	23	93

67	24	21	46	71	81	31	89
44	81	60	35	65	35	54	57
33	78	93	11	13	22	45	71
84	10	77	78	94	61	28	16
71	82	28	17	88	82	93	23

Appendix B

Reasoning Task Practice Tests

Sentence Checking

Below you will see a series of sentences followed by two letters, AB or BA. Each sentence claims to describe the order of the two letters. Your job is to decide whether the sentence is a true or false description of the two letters that follow it and mark the sentence accordingly, circling T for True and F for False.

For example, given the sentence A follows B - AB, you should mark F, since A does not follow B in the pair AB, it precedes it. Had the pair been BA you should of course have marked T since A does follow B in the pair BA.

Now try the following:

1.	B follows A - BA	T	F
2.	A precedes B - AB	T	F
3.	B is followed by A - BA	T	F
4.	A is not followed by B - AB	T	F
5.	B does not precede A - AB	T	F
6.	A is not preceded by B - AB	T	F

Now check your answers with the experimenter.

Name ____________________

Sentence Checking

Training Sheet

1.	A precedes B - AB	T	F	
2.	B follows A - BA	T	F	
3.	B does not precede A - AB	T	F	
4.	A is followed by B - AB	T	F	
5.	A does not precede B - AB	T	F	
6.	B is followed by A - AB	T	F	
7.	A is not preceded by B - BA	T	F	
8.	A is followed by B - AB	T	F	
9.	A precedes B - BA	T	F	
10.	B is not followed by A - BA	T	F	Time ______

Check your time and answers with the experimenter

____

11.	B is not preceded by A - AB	T	F	
12.	A does not follow B - BA	T	F	
13.	B precedes A - BA	T	F	
14.	B is not followed by A - BA	T	F	
15.	A is preceded by B - AB	T	F	
16.	A is followed by B - BA	T	F	
17.	B does not follow A - BA	T	F	
18.	B is preceded by A - AB	T	F	
19.	A is not followed by B - AB	T	F	
20.	A follows B - BA	T	F	Time ______

Check your time and answers